Computer Program for Three Body Break Up Reaction (Commemoration Issue Dedicated to Professor Sakae Shimizu on the Occasion of his Retirement)

AUTHOR(S):

Fukunaga, Kiyoji; Kakigi, Shigeru

Bull. Inst. Chem. Res., Kyoto Univ., Vol. 57, No. 1, 1979

Computer Program for Three Body Break Up Reaction

Kiyoji FUKUNAGA* and Shigeru KAKIGI*

Received October 11, 1978

A FORTRAN program is developed to calculate the energy spectrum for three body break up reation at intermediate energy. Energy spectra are calculated on the basis of AGS (Alt, Grassberger and Sandhas) formalism assuming quasi free scattering with final state interaction. The calculated curves reproduced well energy spectra of ^{3}He in coincidence with protons for ^{3}He(τ, τp) reaction and deuterons for ^{3}He(τ, τd) reaction at 120 MeV.

KEY WORDS Nuclear Reaction ^{3}He(τ, τp) at 120 MeV / Program for QF Scattering with FSI/

I INTRODUCTION

Three body problems could be treated exactly on the basis of Faddeev's equations with given two body interaction potentials and the energy spectrum of nucleons from break up reaction of deuterons by nucleons could be successfully explained using a separable potential for nucleon-nucleon interation[1]. For the case where components of high angular momentum contribute to the two body interaction in the break up reaction, the problem is not so easy because that realistic separable potential has not yet been obtained and a long computer time needs to solve the integral equations. Furthermore if composite particles are concerned in the final state complicated reaction mechanism is presumed. At intermediate energies, however, continuous energy spectra of emitted particles show rather simple shape with large peaks due to quasi free scattering and some times with peaks for final state interaction appearing at low relative energies of the interacting two particles[2]. Then it is reasonable to assume some simplifications in calculation for the break up reaction. Alt *et al.*[3] have derived one dimensional integral equations for the three body scattering problem and derived a scattering amplitude at the special case where, in the first place, a quasi free process produces three particles and in the final state any two particles interact. We have obtained a computer program to calculate this amplitude and using it evaluated energy spectra for the break up reaction of ^{3}He nucleus by ^{3}He beam at 120 MeV.

II EQUATIONS

Break up amplitude for three body break up reaction can be calculated using Eq. (5. 2) in Ref. 3 as follows,

* 福永清二, 柿木 茂: Nuclear Science Research Facility, Institute for Chemical Research, Kyoto University.

$$X_{p_1,1m}(z) = -\sum_{\gamma\neq 1}\langle \mathbf{p}_1|T'_\gamma(z)G_0(z)|1,\ m\ ;\ z\rangle + \sum_{\gamma\neq 1}\langle \mathbf{p}_1|T_1(z)G_0(z)T_\gamma(z)G_0(z)|1,\ m;\ z\rangle, \tag{1}$$

where T'_γ are non separable "amplitude" and small compared with the two body amplitude T_1. In the calculation the following conditions are assumed. 1) two body amplitude T_1 and T'_γ have not any singularity on the energy shell, 2) the Green's function G_0 at the last position in the second term does not given any singularity because the cancellation of amplitudes at two integration angles $\boldsymbol{p}''_1$ and $-\boldsymbol{p}''_1$, and 3) a pole approximation is applied to integrate the other Green's function in the second term. Then the cross section is given as follows,

$$\frac{d^3\sigma}{d\Omega_1 d\Omega_2 dE_1} = \frac{2\pi}{\hbar^2}\cdot\frac{\mu_{in}}{k_{in}}\rho|M_+ + M_-|^2, \tag{2}$$

$$\begin{aligned} M_\pm &= \langle q_1|X_\pm|q_0\rangle \\ &= -\sum_{\gamma\neq 1}\left(\frac{1}{S_{\gamma 1}}\right)^3\langle \mathbf{p}'_\gamma|T'_\gamma(z-q_1^2)|\mathbf{p}_\gamma\rangle\frac{1}{\{\mathbf{p}'_1-\frac{C_{\gamma 1}}{S_{\gamma 1}}(\mathbf{q}_1\mp\mathbf{q}_0)\}^2-Q} \\ &\qquad\times\langle \mathbf{p}'_1-\frac{C_{\gamma 1}}{S_{\gamma 1}}(\mathbf{q}_1-\mathbf{q}_0)|1,\ m;\ z\rangle \\ &\quad+\sum_{\gamma\neq 1}\left(\frac{1}{S_{\gamma 1}}\right)^3\int d\Omega''\langle \mathbf{p}_1|T_1(z-q_1^2)|\mathbf{p}''_1\rangle\frac{\pi}{2}ip''_1\langle \mathbf{p}''_1|T'_\gamma(z-q_\gamma^2)|\mathbf{p}'_\gamma\rangle \\ &\qquad\times\frac{1}{\{\mathbf{p}'_1-\frac{C_{\gamma 1}}{S_{\gamma 1}}(\mathbf{q}_1-\mathbf{q}_0)\}^2-Q}\langle \mathbf{p}'_1-\frac{C_{\gamma 1}}{S_{\gamma 1}}(\mathbf{q}_1\mp\mathbf{q}_0)|1,m;z\rangle, \end{aligned} \tag{3}$$

$$p''^2_1 = z-q_1^2,$$

where ρ is the phase space for factor three body system in the final state. M_+ and M_- are matrix elements for the target break up process and projectile break up process, respectively. The variable p_1^2 and q_1^2 have a dimension of energy and relate to the usual wave vector $\boldsymbol{k}$ and mass m,

$$\left.\begin{aligned} \mathbf{p}_1 &= [2m_2m_3(m_2+m_3)]^{-1/2}(m_3\mathbf{k}_2-m_2\mathbf{k}_3), \\ \mathbf{q}_1 &= [2m_1(m_2+m_3)(m_1+m_2+m_3)]^{-1/2}[m_1(\mathbf{k}_2+\mathbf{k}_3)-(m_2+m_3)\mathbf{k}_1], \end{aligned}\right\} \tag{4}$$

and the variables in the i-jk system are related to the variables in the j-ki system through the following relations,

$$\left.\begin{aligned} \mathbf{p}_2 &= C_{21}\mathbf{p}_1+S_{21}\mathbf{q}_1, \\ \mathbf{q}_2 &= -S_{21}\mathbf{p}_1+C_{21}\mathbf{q}_1. \end{aligned}\right\} \tag{5}$$

where

$$\left.\begin{aligned} C_{21} &= -\left[\frac{m_1m_2}{(m_1+m_3)(m_2+m_3)}\right]^{1/2} = C_{12}, \\ S_{21} &= \sqrt{1-C_{21}^2}, \end{aligned}\right\} \tag{6}$$

Four types of potential are assumed in the calculation of the initial interaction, that is Gaussian type, Yukawa type, Woods Saxson type and Woods Saxson for real potential with the first derivative of Woods Saxson for imaginary potential,

$$\langle \mathbf{p}_\tau | T_\tau(z-q_\tau^2) | \mathbf{p}_\tau' \rangle = T_\tau(\mathbf{p}_\tau'-\mathbf{p}_\tau), \tag{7}$$

$$= -\pi^{3/2}\frac{V}{\alpha^3}\exp\left[-\frac{(\mathbf{p}_\tau'-\mathbf{p}_\tau)^2}{4\alpha^2}\right], \qquad \text{for Gaussian} \tag{8}$$

$$= -4\pi V\left[\frac{1}{\alpha_1^2+(\mathbf{p}_\tau'-\mathbf{p}_\tau)^2}+\frac{\eta}{\alpha_2^2+(\mathbf{p}_\tau'-\mathbf{p}_\tau)^2}\right], \qquad \text{for Yukawa} \tag{9}$$

$$= \int d\mathbf{r}^3 V(r)\, e^{i(\mathbf{p}_\tau-\mathbf{p}_\tau')\mathbf{r}}, \qquad \text{for Woods Saxon } V(r). \tag{10}$$

The form factor of the target nucleus is assumed as,

$$\langle \mathbf{p}_1 | 1,\ m;\ z\rangle = (z-q_0^2)\,\phi_{1m}(\mathbf{p}_1),$$

$$\phi_{1m}(\mathbf{p}_1) = \frac{\sqrt{\alpha}}{\pi}\ \frac{1}{\alpha^2+p_1^2}\,. \tag{11}$$

S wave final state interaction between particle 2 and particle 3 relates to the effective range parameters at zero energy limit in the two body scattering,

$$|\langle \mathbf{p}_1 | T_1(z-q_1^2) | \mathbf{p}_1' \rangle|^2 = \frac{C^2(\eta)}{4\pi^2}\cdot\frac{1}{C^2(\eta)\,q^2+\left(-\frac{1}{a}+\frac{1}{2}rq^2\right)}, \tag{12}$$

$$q^2 = (\mathbf{p}_1'-\mathbf{p}_1)^2,$$

$$C^2(\eta) = 2\pi\eta/[\exp(2\pi\eta)-1],$$

$$\eta = z_2 z_3 e^2/\hbar v,$$

where $C(\eta)$ is the Coulomb penetration factor. For the l-th partial wave interaction in the final state Brait-Wigner type resonance form is assumed as follows,

$$|\langle \mathbf{p}_1 | T_1(z-q_1^2) | \mathbf{p}_1' \rangle|_l^2 = A\frac{\Gamma_l^2}{(z-q_l^2-E_l)^2+\frac{1}{4}\Gamma_l^2}P_l(\cos\omega). \tag{13}$$

The angular integral of Eq. (3) is done analytically where the angular momentum of l is less than or equal to 2. The values of parameters in Eq. (8), (9), and (11) are tranformed from the radial parameters in fm using following relation,

$$\alpha^2_{\mathrm{MeV}} = \frac{\gamma}{\mu a_{\mathrm{fm}}}, \qquad \gamma = \frac{41.6}{2},$$

μ: reduced mass

III COMPUTER PROGRAM

The computer program "**AGSIA**" calculates the three body break up cross section on the basis of AGS formalism. Seven types of card have to read in the format of free field as the input data. Three body kinematics is calculated using a subprogram "**KINEMA**" which is the same as the program developed by Ohlsen[4], and the numerical integration of Eq. (10) is made using a sub-program "**SMPSON**" which is a usual program of Simpson Integral. The matrix element in Eq. (3) is calculated using a sub-program "**XMAT**". Four types of initial interaction can be selected by **KCODE4** and five print out format can be selected by **KCODE3.** All calculated energy spectra are print out in units of $10^{-26}\mathrm{cm}^2/\mathrm{sr}^2\cdot\mathrm{MeV}$. as a function of the laboratory energy of particle 1. The FORTRAN programs are given in an Appendix.

The energy spectrum of ^{3}He in coincidence with protons for $^3\mathrm{He}(\tau,\ \tau p)d$ reaction

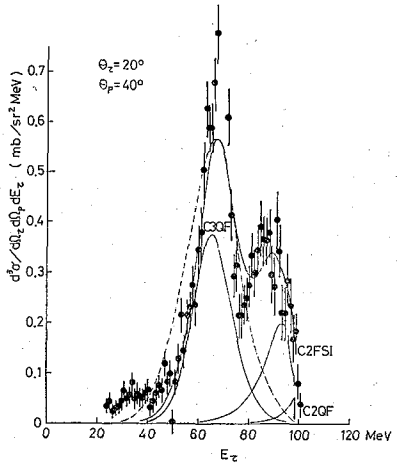

Fig. 1. Energy spectrum projected for the ^{3}He(τ, τp)d reactions at θ_τ=20° and θ_p=40°. All solid curves are calculated on the basis of the AGS formalism. The dashed curve shows the calculated one of the simple spectator model.

at 120 MeV was calculated using the program of "**AGSIA**". Figure 1 shows the calculated curves at the angular set θ_τ=20°, θ_p=40° and φ_p=0° (opposite side of, and in coplanar with, the beam) and shows the experimental energy spectrum which was obtained from the data in Ref. 2. The curves denoted as **C2QF** and **C2FSI** are calculated using only the first term at γ=2 and the second term at γ=2 in Eq. (1). The former corresponds to the cross section assuming the quasi free scattering of particle 1 (^{3}He) and particle 3(unobserved particle) and the latter corresponds to that for quasi scattering with the final state interaction of particle 2 and particle 3. The dashed curve is calculated using a simple impulsed spectator model. Nevertheless a normalization constant was needed to reproduce the experimental energy spectrum, the calculated energy spectrum is repoduced well using a reasonable parameter set.

ACKNOWLEDGMENT

Authors would like to thanks to Mr. T. Ohsawa, Dr. S. Tanaka, and Mr. A. Okihana for their usefull discussions and cooperations to obtain the data of ^{3}He(τ, τp)d reaction. Numerical calculation was made by FACOM 230 computer at the Institute for Chemical Research of Kyoto University.

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Appendix

Instructions for use of "AGSIA"

Card 1 (general conditions in the calculation)

:KCODEI, KCODE2, KCODE3, KCODE4, IK, NO, FACT

KCODE1 =1 print subtitle "XM3 IS NOT A COMPOSITE PARTICLE"
2 print subtitle "XM3=XM4+XM5 AND BREAKS TO SINGLET DEUTERON"
3 print subtitle "XM3=XM4+XM5 AND BREAKS TO TRIPLET p+n" SYSTEM"

if any number is chosen, the program does not change to calculate the reaction

KCODE2 =0 calculate the target breakup reaction ; $M=M_+$
1 calculate the projectile breakup reaction ; $M=M_-$
2 calculate the target breakup plus the projectile breakup reaction ; $M=M_++M_-$

KCODE3 =0 print out the kinematics of three body breakup reaction
1 print out all reaction amplitudes and phase space factor
2 print out the final cross sections
3 print out the cross sections for (1-2) quasi free, the cross sections for (1-3) quasi free and the final cross sections
4 print out all cross sections of components in Eq. (3) and the final cross sections

KCODE4 =0 initial interaction of Gaussian type
1 initial interation of double Yukawa type
2 initial interaction of Woods-Saxson type
3 initial interaction of Woods-Saxson (real) with the first derivative of the Woods-Saxson (imaginary)

LK number of resonance in the final state interaction

NO number of angular set

FACT factor of the second term by the first term in Eq. (3), and set 1 in the usual calculation.

Card 2 (kinematical parameters)

:XMP, XMT, XM1, XM2, XM3, Q, EPL, DE1L, ZZ

XMP mass of the projectile in atomic mass unit

XMT Mass of the target in atomic mass unit

XM1 Mass of the particle 1 in atomic mass unit

XM2 mass of the particle 2 in atomic mass unit

XM3 mass of the particle 3 in atomic mass unit

Q reaction Q value in MeV

EPL incident energy in MeV

DE1L energy increment in MeV

ZZ product of electric charges Z_2 and Z_3

Card 3 (form factor and effective range parameters)

:ALPHTO, ALPHAO, ERANGT

ALPHTO width of the from factor in fm

ALPHAO scattering length in fm

ERAMGT effective range in fm

Card 4 (potential parameters for the first step interaction between particle 1 and particle 2.)

:VTPO1, RHTPO1, DHTPO1, YETAP1, VTPO2, RHTPO2, DHTPO2, YETAP2

VTPO1 real well depth in MeV

RHTPO1 real well width in fm

DHTPO1 real well diffuseness (for Gaussian or Woods-Saxson) or second well width in fm (for double Yukawa)

YETAP1 ratio of second Yukawa potential to the first Yukawa potential

VTPO2 imaginary well depth in MeV

RHTPO2 imaginary well width in fm

DHTPO2 imaginary well diffuseness (for Gaussian or Woods-Saxson) or the second well

width in fm (for double Yukawa)

YETAP2 ratio of the imaginary depth of second Yukawa to that of first Yukawa

Card 5 (potential parameters for the first step interaction between particle 1 and particle 3)

:VTDO1, RHTDO1, DHTDO1, YETAD1, VTDO2, RHXDO2, DHTDO2, YETAD2

similar to the Card 4

Card 6 (resonance parameters for the S wave final state interaction)

:COEF(1), ER(1) WIDTH(1)

COEF(1) coefficient of the Brait-Wigner resonance

ER(1) resonance energy in MeV

WIDTH(1) resonance width in MeV

If the resonances for the P wave and the D wave final state interactions are calculated, the Card 7 and Card 8 are used for the resonance parameters. If any resonance is not calculate, the COEF(1) in the Card 6 must be equal to zero. And the Card of angular set follows to the resonance Card.

Card 7 (angular set)

:TH1R, TH2R, PHI2

TH1R polar angle of particle 1 in degrees in the laboratory

TH2R polar angle of particle 2 in degrees

PHI2 azimuthal angle of particle 2 in degrees. Set zero when the detectors for particle 1 and particle 2 are set opposite side of, in coplaner, with, the incident beam.

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SOURCE    LIST

          C      PROGRAM  AGS1A                                                  AGS00000
          C      CROSS SECTION IN UNITS OF 10**(-26) CM**2/MEV                  AGS00010
          C      AMPLITUDE IN UNITS OF 10**(-13) CM/(MEV**0.5)                  AGS00020
          C      ALPHA IN FERMI                                                 AGS00030
          C      W IN MEV, RM IN FERMI, PM IN FERMI                             AGS00040
          C      KCODE2  0  TARGET BREAK                                        AGS00050
          C              1     PROJECTILE BREAK                                AGS00060
          C              2     TARGET BREAK AND PROJECTILE BREAK               AGS00070
          C                                                                     AGS00080
0001      C      COMMON /AUATA/E1L(300),F2L(300,2),E23(300),E31(300,3),E12(300,2)AGS00090
          1                   ,TH1C(300),TH2C(300,2),TH3C(300,2),THCP1(300,2)  AGS00100
          1                   ,THCP2(300,2),THCP3(300,2),RHO1(300,2),RHO2(300,2)AGS00110
          1                   ,TH3L(300,2),PH13L(300,2)                        AGS00120
0002      C      COMMON /AINPT/XMP,XMT,XM1,XM2,XM3,Q,EPL,TH1L,TH2L,PH12L          AGS00130
0003      C      COMMON /RESLT/A12(2),A13(2),AL12(2),AL13(2)                    AGS00140
0004      C      COMMON/APUIN/ALPHT,ALPHA,ERANGA,VTPO(2),RHTPO(2),DHTPO(2),YETAP(2)AGS00150
          1,VTPO(2),RHTPO(2),DHTPO(2),YETAO(2)                                  AGS00160
0005      C      COMMON /RESON/COEF(4),ER(4),WIDTH(4)                           AGS00170
0006      C      COMMON /OUTPT/A2(2,2,300),A3(2,2,300),AL2(2,2,300),AL3(2,2,300)AGS00180
0007      C      COMMON /KCODE/KCODE1,KCODE2,KCODE3,KCODE4                      AGS00190
          C                                                                     AGS00200
          C      READ INPUT DATA                                                AGS00210
0008      C      READ(5,*) KCODE1,KCODE2,KCODE3,KCODE4,LK,NO,FACT4              AGS00220
0009      C      IF(KCODE3.EQ.0) GOTO 1                                         AGS00230
0010      C      WRITE(6,1000)                                                  AGS00240
0011      C      PAI=3.1415927                                                  AGS00250
0012      C      WRITE(6,1010) KCODE1,KCODE2,KCODE3,KCODE4,LK,NO,FACT4          AGS00260
0013      C      GAMMA=1.0/41.79                                                AGS00270
0014      C      FACT1=SQRT(1.0/(2.0*GAMMA))                                    AGS00280
0015      C      FACT=FACT1                                                     AGS00290
0016      C    1 READ(5,*) XMP,XMT,XM1,XM2,XM3,Q,EPL,DELE1L,ZZ                  AGS00300
0017      C      WRITE(6,1001) XMP,XMT,XM1,XM2,XM3,Q,EPL,ZZ                     AGS00310
0018      C      IF(KCODE3.EQ.0) GOTO 40                                        AGS00320
          C                                                                     AGS00330
          C      READ THE DATA OF FORM FACTOR FOR THE TARGET                    AGS00340
0019      C      READ(5,*) ALPHTD,ALPHAD,ERANGT                                 AGS00350
0020      C      WRITE(6,1002) ALPHTD,ALPHAD,ERANGT                             AGS00360
          C                                                                     AGS00370
          C      READ THE DATA FOR INTERACTION WITH XM2                         AGS00380
0021      C      READ(5,*) VTPO1,RHTPO1,DHTPO1,YETAP1,VTPO2,RHTPO2,DHTPO2,YETAP2AGS00390
0022      C      WRITE(6,1003)VTPO1,RHTPO1,DHTPO1,YETAP1,VTPO2,RHTPO2,DHTPO2,YETAP2AGS00400
0023      C      VTPO(1)=VTPO1                                                  AGS00410
0024      C      VTPO(2)=VTPO2                                                  AGS00420
0025      C      SXM12=SQRT(XM1*XM2/(XM1+XM2))                                  AGS00430
0026      C      SXM13=SQRT(XM1*XM3/(XM1+XM3))                                  AGS00440
0027      C      SXM23=SQRT(XM2*XM3/(XM2+XM3))                                  AGS00450
0028      C      RHTPO(1)=FACT/(SXM12*RHTPO1)                                   AGS00460
0029      C      RHTPO(2)=FACT/(SXM12*RHTPO2)                                   AGS00470
0030      C      YETAP(1)=YETAP1                                                AGS00480
0031      C      YETAP(2)=YETAP2                                                AGS00490
0032      C      DHTPO(1)=1.0                                                   AGS00500
0033      C      DHTPO(2)=1.0                                                   AGS00510
0034      C      IF(YETAP1-EQ.0.0) GOTO 3                                       AGS00520
0035      C      DHTPO(1)=FACT/(SXM12*DHTPO1)                                   AGS00530
0036      C    3 IF(YETAP2-EQ.0.0) GOTO 5                                       AGS00540
0037      C      DHTPO(2)=FACT/(SXM12*DHTPO2)                                   AGS00550
0038      C    5 CONTINUE                                                       AGS00560
0039      C      ALPHT=FACT1/(SXM23*ALPHTD)                                     AGS00570
0040      C      ALPHA=FACT1/(SXM23*ALPHAD)                                     AGS00580
0041      C      ERANGA=FACT1/(SXM23*ERANGT)                                    AGS00590
0042      C      DO 10 I=1,9                                                    AGS00600
0043      C      COEF(I)=0.0                                                    AGS00610
0044      C   10 CONTINUE                                                       AGS00620
          C                                                                     AGS00630
          C      READ THE DATA FOR INTERACTION WITH XM3                         AGS00640
0045      C      READ(5,*) VTDO1,RHTDO1,DHTDO1,YETAD1,VTDO2,RHTDO2,DHTDO2,YETAD2AGS00650
0046      C      WRITE(6,1004) VTDO1,RHTDO1,DHTDO1,YETAD1,VTDO2,RHTDO2,DHTDO2,YETAD2AGS00660
0047      C      VTDO(1)=VTDO1                                                  AGS00670
0048      C      VTDO(2)=VTDO2                                                  AGS00680
0049      C      RHTDO(1)=FACT/(SXM13*RHTDO1)                                   AGS00690
0050      C      RHTDO(2)=FACT/(SXM13*RHTDO2)                                   AGS00700
0051      C      YETAD(1)=YETAD1                                                AGS00710
0052      C      YETAD(2)=YETAD2                                                AGS00720
0053      C      DHTDO(1)=1.0                                                   AGS00730
0054      C      DHTDO(2)=1.0                                                   AGS00740
0055      C      IF(YETAD1-EQ.0.0) GOTO 23                                      AGS00750
0056      C      DHTDO(1)=FACT/(SXM13*DHTDO1)                                   AGS00760
0057      C   23 IF(YETAD2-EQ.0.0) GOTO 25                                      AGS00770
0058      C      DHTDO(2)=FACT/(SXM13*DHTDO2)                                   AGS00780
0059      C   25 CONTINUE                                                       AGS00790
0060      C      DO 38 KL=1,LK                                                  AGS00800
0061      C      READ(5,*) COEF(KL),ER(KL),WIDTH(KL)                            AGS00810
0062      C      L=KL-1                                                         AGS00820
0063      C      WRITE(6,1005) L,COEF(KL),ER(KL),WIDTH(KL)                      AGS00830
0064      C   38 CONTINUE                                                       AGS00840
0065      C   40 CONTINUE                                                       AGS00850
0066      C      DO 300 III=1,NO                                                AGS00860
0067      C      READ(5,*) TH1L,TH2L,PH12L                                      AGS00870
0068      C      WRITE(6,1007) TH1L,TH2L,PH12L                                  AGS00880
          C                                                                     AGS00890
          C      COMPUTE KINEMATICS                                             AGS00900
0069      C      CALL KINEMA(E1L,MAX,F1LMIN,E2LMAX,F2LMIN,TH1MAX,TH2MAX,        AGS00910
          1 XMP,XMT,XM1,XM2,XM3,Q,FPL,DPLE1L,TH1L,TH2L,PH12L,LMAX,LMIN,        AGS00920
          1 ICODE)                                                              AGS00930
0070      C      IF(KCODE3.EQ.0) GOTO 110                                       AGS00940
0071      C      ERELTV=XM1*EPL/(XMP+XMT)                                       AGS00950
0072      C      ETOT=Q+ERELTV                                                  AGS00960
0073      C      XMPT=XMP*XMT/(XMP+XMT)                                         AGS00970
0074      C      XM23=XM2*XM3/(XM2+XM3)                                         AGS00980
0075      C      XM123=XM1*(XMP+XM3)/(XM1+XM2+XM3)                              AGS00990
0076      C      FACT3=PAI**2/SQRT(2.0)                                         AGS01000
0077      C      FACT2=FACT3*SQRT(SQRT((XMPT/ERELTV))/(GAMMA*XM123**3*XM23**1.5))AGS01010
0078      C      G1O=SQRT(ERELTV)                                               AGS01020
0079      C      DO 200 KL=1,LK                                                 AGS01030
0080      C      L=KL-1                                                         AGS01040
0081      C      DO 100 I=LMIN,LMAX                                             AGS01050
0082      C      G1=SQRT(E1DT-E23(I))                                           AGS01060
0083      C      P1=SQRT(E23(I))                                                AGS01070
0084      C      E1=E1L(I)                                                      AGS01080
0085      C      E2=E2L(I,1)                                                    AGS01090
0086      C      E3=FPL+Q-E1L(I)-E2L(I,1)                                       AGS01100
0087      C      DO 90 M=1,KCODE2                                               AGS01110
0088      C      IF(KCODE2.EQ.1.AND.M.EQ.1) GO TO 50                            AGS01120
0089      C      IF(KCODE2.EQ.2.AND.M.EQ.2) GO TO 50                            AGS01130
          C                                                                     AGS01140
          C      TARGET BREAK                                                   AGS01150
0090      C      N1=1                                                           AGS01160
0091      C      THETA1=TH1C(I)                                                 AGS01170
0092      C      GO TO 60                                                       AGS01180
          C                                                                     AGS01190
          C      PROJECTILE BREAK                                               AGS01200
0093      C   50 THETA1=180.0-TH1C(I)                                           AGS01210
0094      C      N1=2                                                           AGS01220
0095      C   60 CONTINUE                                                       AGS01230
0096      C      THETA2=180.0-THCP1(I,1)                                        AGS01240
0097      C      PHI2=PH12L                                                     AGS01250
          C                                                                     AGS01260
          C      COMPUTE A.G.S. AMPLITUDES                                      AGS01270
0098      C      CALL XMAT(Q,Q1,P1,E1,E2,E3,THETA1,THETA2,PHI2,ZZ,L)             AGS01280
0099      C      DO 70 J=1,2                                                    AGS01290
0100      C      A2(N1,J,I)=AL2(J)*FACT2                                        AGS01300
0101      C      A3(N1,J,I)=AL3(J)*FACT2                                        AGS01310
0102      C      AL2(N1,J,I)=AL12(J)*FACT2*FACT4                                AGS01320
0103      C      AL3(N1,J,I)=AL13(J)*FACT2*FACT4                                AGS01330
0104      C      IF(ABS(A2(N1,J,I)).LT.1.0E-37) A2(N1,J,I)=0.0                  AGS01340
0105      C      IF(ABS(A3(N1,J,I)).LT.1.0E-37) A3(N1,J,I)=0.0                  AGS01350
0106      C      IF(ABS(AL2(N1,J,I)).LT.1.0E-37) AL2(N1,J,I)=0.0                AGS01360
0107      C      IF(ABS(AL3(N1,J,I)).LT.1.0E-37) AL3(N1,J,I)=0.0                AGS01370
0108      C   70 CONTINUE                                                       AGS01380
0109      C   90 CONTINUE                                                       AGS01390
0110      C  100 CONTINUE                                                       AGS01400
0111      C  110 CONTINUE                                                       AGS01410
0112      C      CALL PRINT(LMIN,LMAX,KCODE1,KCODE2,KCODE3)                     AGS01420
0113      C      IF(KCODE3.EQ.0) GOTO 300                                       AGS01430
0114      C  200 CONTINUE                                                       AGS01440
0115      C  300 CONTINUE                                                       AGS01450
0116      C      STOP                                                           AGS01460
0117      C 1000 FORMAT(1H1,'ENERGY SPECTRUM OF THREE BODY BREAK UP REACTION')  AGS01470
0118      C 1001 FORMAT(1H ,'MASS-P=',1,2*3H=',5F10.4,'   Q=',F10.4,'   FPL=',F10.4,AGS01480
          1'   ZZ=',F10.4)                                                      AGS01490
0119      C 1002 FORMAT(1H ,'ALPHT,ALPHA,ERANGT=',3F10.4)                       AGS01500
0120      C  102 FORMAT(1H ,'POT. PARAM. WITH XM2=',8F10.4)                     AGS01510
0121      C 1003 FORMAT(1H ,I4,'-TH RESONANCE  COEF=',F10.4,'   ERES=',F10.4,   AGS01520
          1'   WIDTH=',F10.4)                                                   AGS01530
0122      C  106 FORMAT(1H ,'POT. PARAM. WITH XM3=',8F10.4)                     AGS01540
0123      C 1007 FORMAT(1H1,'TH1L=',F10.4,'   TH2L=',F10.4,'   PH12L=',F10.4)  AGS01550
0124      C 1010 FORMAT(1H ,'KCODE1-2,3,4=,LMAX=,ANGLE SET AND FACT4=',6I5,F10.4)AGS01560
0125      C      END                                                            AGS01570
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0001      C      SUBROUTINE XMAT(Q10,Q1,P1,E1,E2,E3,THETA1,THETA2,PHI2,ZZ,L)     AGS01580
0002      C      COMMON /RESLT/A12(2),A13(2),AL12(2),AL13(2)                    AGS01590
0003      C      COMMON/APUTN/ALPHT,ALPHA,ERANGA,VTPO(2),RHTPO(2),DHTPO(2),YETAP(2)AGS01600
          1,VTPO(2),RHTDO(2),DHTDO(2),YETAD(2)                                  AGS01610
0004      C      COMMON /AINPT/XMP,XMT,XM1,XM2,XM3,Q,EPL,TH1L,TH2L,PH12L        AGS01620
0005      C      COMMON /RESON/COEF(4),ER(4),WIDTH(4)                           AGS01630
0006      C      COMMON /KCODE/KCODE1,KCODE2,KCODE3,KCODE4                      AGS01640
0007      C      DIMENSION FL(2),TT1(2),TT2(2),TT3(2)                           AGS01650
0008      C      K=KCODE1                                                       AGS01660
0009      C      PAI=3.1415927                                                  AGS01670
0010      C      COS1=COS(THETA1*PAI/180.0)                                     AGS01680
0011      C      COS2=COS(THETA2*PAI/180.0)                                     AGS01690
0012      C      SIN1=SIN(THETA1*PAI/180.0)                                     AGS01700
0013      C      SIN2=SIN(THETA2*PAI/180.0)                                     AGS01710
0014      C      CPH2=COS(PHI2*PAI/180.0)                                       AGS01720
0015      C      XMTOT=XM1+XM2+XM3                                              AGS01730
0016      C      C12=SQRT(XM1*XM2/((XM2+XM3)+(XM1+XM3)))                        AGS01740
0017      C      C13=SQRT((XM1*XM3/((XM2+XM3)+(XM1+XM2))))                      AGS01750
0018      C      S12=SQRT(1.0-C12*C12)                                          AGS01760
0019      C      S13=SQRT(1.0-C13*C13)                                          AGS01770
0020      C      GAMA12=C12/S12                                                 AGS01780
0021      C      GAMA13=C13/S13                                                 AGS01790
0022      C      AP2=Q1*COS2-Q10*(COS1*COS2-SIN1*SIN2*CPH2)                     AGS01800
0023      C      AP3=-AP2                                                       AGS01810
0024      C      T2=Q1*Q1+Q10*Q10-2.0*Q1*Q10*COS1                               AGS01820
0025      C      T1=SQRT(T2)                                                    AGS01830
0026      C      P12STR=SQRT(E2*(XM2+XM3)/XM3)                                  AGS01840
0027      C      P13STR=SQRT(E3*(XM2+XM3)/XM2)                                  AGS01850
0028      C      QD2=T1/S12                                                     AGS01860
0029      C      QD3=T1/S13                                                     AGS01870
0030      C      DO 45 I=1,2                                                    AGS01880
0031      C      K=K-CODE4                                                      AGS01890
0032      C      IF(KCODE4-NE.3) GOTO 42                                        AGS01900
0033      C      K=K**(1-1)*10                                                  AGS01910
0034      C   42 CONTINUE                                                       AGS01920
0035      C      CALL FISTER(T1F,+QD3,VTPO(I),RHTPO(I),DHTPO(I),YETAP(I),K)     AGS01930
0036      C      TT3(I)=T1F                                                     AGS01940
0037      C      CALL FISTER(T1F,+QD2,VTDO(I),RHTDO(I),DHTDO(I),YETAD(I),K)     AGS01950
0038      C      TT2(I)=T1F                                                     AGS01960
0039      C   45 CONTINUE                                                       AGS01970
0040      C   60 CONTINUE                                                       AGS01980
          C                                                                     AGS01990
          C      COMPUTE FORM FACTORS                                           AGS02000
0041      C      GFAM12=FORM(ALPHT,P12STR)/(P12STR**2-Q)                        AGS02010
0042      C      GFAM13=FORM(ALPHT,P13STR)/(P13STR**2-Q)                        AGS02020
0043      C      CALL FL(GFAM,P1,L,ZZ)                                          AGS02030
          C                                                                     AGS02040
          C      COMPUTE AMPLITUDES                                             AGS02050
0044      C      FACT=PI                                                        AGS02060
0045      C      FACT12=Q/(ABS(S12)**3)                                         AGS02070
0046      C      FACT13=Q/(ABS(S13)**3)                                         AGS02080
0047      C      DO 65 I=1,2                                                    AGS02090
0048      C      A12(I)=FACT12*FT2(I)*GFAM12                                    AGS02100
0049      C      A13(I)=FACT13*TT3(I)*GFAM13                                    AGS02110
0050      C   65 CONTINUE                                                       AGS02120
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      GL2=SQRT(ALPHT/PAI)*(GL(AP2*SQRT(ABS(Q))*P1*T1*GAMA12*L)-      AGS02130
     1GL(AP2*ALPHT*P1*T1*GAMA12*L))/(ALPHT**2*Q)                     AGS02140
      GL3=SQRT(ALPHT/PAI)*(GL(AP3*SQRT(ABS(Q))*P1*T1*GAMA13*L)-      AGS02150
     1GL(AP3*ALPHT*P1*T1*GAMA13*L))/(ALPHT**2*Q)                     AGS02160
      AL12(1)=(0.5*PAI*FACT12)*FACT*(FLM(1)*TT2(2)*FLM(2)*TT2(1))*GL2  AGS02170
      AL12(2)=(0.5*PAI*FACT12)*FACT*(-FLM(1)*TT2(1)*FLM(2)*TT2(2))*GL2 AGS02180
      AL13(1)=(0.5*PAI*FACT13)*FACT*(FLM(2)*TT3(1)*FLM(1)*TT3(2))*GL3  AGS02190
      AL13(2)=(0.5*PAI*FACT13)*FACT*(-FLM(1)*TT3(1)*FLM(2)*TT3(2))*GL3 AGS02200
      RETURN                                                         AGS02210
      END                                                            AGS02220


      SUBROUTINE FL(FLM,P1,L,ZZ)                                     AGS02230
C                                                                    AGS02240
C     SUBROUTINE FOR F.S.I.                                          AGS02250
C     ZZ=Z1*Z2   ELECTRIC CHARGES                                    AGS02260
C     L   ANGULAR MOMENTUM OF THE FSI STATE                          AGS02270
C     L-TH RESONANCE   BRAIT WIGNER TYPE                             AGS02280
      COMMON/AMOTH/ALPHT,ALPHA,ENANGA,VTHQ(2),RHTPO(2),DHTPO(2),YETAP(2)AGS02290
     1,VTOU(2),XMTOD(2),DHTOD(2),YETAD(2)                            AGS02300
      COMMON /AINPT/XMP,XMT,XM1,XM2,XM3,Q,EPL,TH1L,TH2L,PHI2L        AGS02310
      COMMON /RESON/COFF(4),FP(4),WIDTH(4)                           AGS02320
      DIMENSION FLM(2)                                               AGS02330
      PAI=3.1415927                                                  AGS02340
      FACT=0.5/(PAI**2)                                              AGS02350
      FLM=C.0                                                        AGS02360
      FLN1=0.0                                                       AGS02370
      L=L-4                                                          AGS02380
      IF(L) 10,5,5                                                   AGS02390
    5 FLM(1)=0.0                                                     AGS02400
      FLM(2)=0.0                                                     AGS02410
      RETURN                                                         AGS02420
   10 L1=L+1                                                         AGS02430
      IF(ZZ) 20,15,20                                                AGS02440
   15 C=1.0                                                          AGS02450
      GO TO 23                                                       AGS02460
   20 YETA=U.2226*ZZ*SQRT(U.5*XM2*XM3/(XM2+XM3))/P1                  AGS02470
      YETA2P=2.0*PAI*YETA                                            AGS02480
      C=YETA2P/(EXP(YETA2P)-1.0)                                     AGS02490
   23 CONTINUE                                                       AGS02500
      IF(L.NE.0) GOTO 25                                             AGS02510
      ALPH=ALPHA-1.5*P1**2/ENANGA                                    AGS02520
      G2=ALPH**2+(P1*C)**2                                           AGS02530
      FLM=-C*ALPH/G2                                                 AGS02540
      FLN1=C*C**P1/G2                                                AGS02550
   25 CONTINUE                                                       AGS02560
      IF(COFF(L1)) 30,35,30                                          AGS02570
   30 DENOM=(P1**2)-P*(L1))**2+WIDTH(L1)**2/4.0                      AGS02580
      FLR=(XDTH(L1)**2/2.0)*COFF(L1)/DENOM                           AGS02590
      FLI=(P1**2-P*(L1))*WIDTH(L1)*COFF(L1)/DENOM                    AGS02600
      GO TO 40                                                       AGS02610
   35 FLR=0.0                                                        AGS02620
      FLI=0.0                                                        AGS02630
   40 FLM(1)=FACT*(FLM+FLR/P1)                                       AGS02640
      FLM(2)=FACT*(FLN1+FLI/P1)                                      AGS02650
      RETURN                                                         AGS02660
      END                                                            AGS02670


      SUBROUTINE FISTEP(TIF,V,RH,DH,YETAR,K4)                        AGS02680
C                                                                    AGS02690
C     FIRST STEP TRANSITION AMPLITUDES                               AGS02700
C     K4=  0    GAUSS TYPE POTENTIAL                                 AGS02710
C          1    YUKAWA TYPE                                          AGS02720
C          2    MODS SAXON TYPE                                      AGS02730
C          3    REAL PART=MODS SAXON AND IMAG=1-ST DERIV             AGS02740
      DIMENSION P(10)                                                AGS02750
      PAI=3.1413927                                                  AGS02760
      IF(K4.EQ.0) GOTO 10                                            AGS02770
      IF(K4.EQ.1) GOTO 20                                            AGS02780
      GO TO 30                                                       AGS02790
   10 A=SQRT(PAI)/RH                                                 AGS02800
      B=U/(2.0*RH)                                                   AGS02810
      B2=-B*B                                                        AGS02820
      TIF=-V*EXP(B2)*A**3                                            AGS02830
      RETURN                                                         AGS02840
   20 A=-4.0*PAI*V                                                   AGS02850
      B1=(RH**2+U**2)*RH                                             AGS02860
      B2=(DH**2+U**2)*DH                                             AGS02870
      TIF=A*(1.0/B1+YETAR/B2)                                        AGS02880
      RETURN                                                         AGS02890
   30 A=U.0                                                          AGS02900
      R=10.0*RH                                                      AGS02910
      DEL=0.01                                                       AGS02920
      IMAX=200                                                       AGS02930
      P(1)=K                                                         AGS02940
      P(2)=V                                                         AGS02950
      P(3)=RH                                                        AGS02960
      P(4)=DH                                                        AGS02970
      P(5)=K4                                                        AGS02980
      CALL SMPSON(P,A,R,DEL,IMAX,SI1,S,N,IER)                        AGS02990
      IER=IER+1                                                      AGS03000
      GOTO(40,50,50,50,40),IER1                                      AGS03010
   40 TIF=-4.0*PAI*V*S/(W*DH*DH)                                     AGS03020
      RETURN                                                         AGS03030
   50 TIF=0.0                                                        AGS03040
      RETURN                                                         AGS03050
      END                                                            AGS03060
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      FUNCTION GL(ALPHA,P,T,GAMMA,L)                                 AGS03070
C                                                                    AGS03080
C     ANGULAR INTEGRAL                                               AGS03090
      PAI=3.1413927                                                  AGS03100
      BETA2=ALPHA*ALPHA+P*P+GAMMA*GAMMA*T*T                          AGS03110
      E=BETA2+BETA2-(T*T-A*A)*4.0*GAMMA*GAMMA*P*P                    AGS03120
      F=-4.0*BETA2*GAMMA*P*A                                         AGS03130
      G=4.0*(GAMMA*P*T)**2                                           AGS03140
      S1=ABS(E+F+G)                                                  AGS03150
      S2=ABS(E-F+G)                                                  AGS03160
      SP=SQRT(S1)                                                    AGS03170
      SN=SQRT(S2)                                                    AGS03180
      SG=SQRT(G)                                                     AGS03190
      GA=2.0*PAI/SG                                                  AGS03200
      IF(G.EQ.0) GOTO 10                                             AGS03210
      GO=GA*ALOG((1.0+2.0*SG/(BETA2+SG))                             AGS03220
      GO TO 15                                                       AGS03230
   10 GO=4.0*PAI/BETA2                                               AGS03240
   15 CONTINUE                                                       AGS03250
      IF(L.EQ.3) GO TO 40                                            AGS03260
      IF(L.EQ.2) GO TO 30                                            AGS03270
      IF(L.EQ.1) GO TO 20                                            AGS03280
      GL=GO                                                          AGS03290
      GO TO 999                                                      AGS03300
   20 GA1=2.0*PAI*(SP-SN)/G                                          AGS03310
      GB1=0.5*F*GO/G                                                 AGS03320
      GL=GA1-GB1                                                     AGS03330
      GO TO 999                                                      AGS03340
   30 GA2=0.75*PAI/(G*G)                                             AGS03350
      GB2=(2.0*G-3.0*F)*SP+(2.0*G+3.0*F)*SN                          AGS03360
      GC2=(9.0*F*F-12.0*G*E)/(4.0*G*G)                               AGS03370
      GL=GA2*GB2+0.5*(GC2-1.0)*GO                                    AGS03380
      GO TO 999                                                      AGS03390
   40 GA3=3.0*PAI*(SP-SN)/G                                          AGS03400
      GB3=5.0*PAI/(2.0*G**3)                                         AGS03410
      GC3=(2.0*G*G-10.0*G*F+15.0*F*F-16.0*G*E)                       AGS03420
      GD3=GC3*2U.0*G*F                                               AGS03430
      GE3=GC3*SP-GD3*SN                                              AGS03440
      GF3=0.75*F/G                                                   AGS03450
      GH3=(25.0*F*F-60.0*G*E)*F/(32.0*G**3)                          AGS03460
      GL=GA3-GH3*GE3-(GF3+GH3)*GO                                    AGS03470
  999 CONTINUE                                                       AGS03480
      RETURN                                                         AGS03490
      END                                                            AGS03500


      FUNCTION FORM(ALPHA,P)                                         AGS03510
C                                                                    AGS03520
C     FORM FACTOR OF HERTIUM-3                                       AGS03530
      PAI=3.1415927                                                  AGS03540
      FORM=SQRT(ALPHA)/(PAI*(ALPHA*ALPHA+P*P))                       AGS03550
      RETURN                                                         AGS03560
      END                                                            AGS03570


      SUBROUTINE SMPSON(P,A,B,DEL,IMAX,SI1,S,N,IER)                  AGS03580
      DIMENSION P(10)                                                AGS03590
C                                                                    AGS03600
      SI1=0.0                                                        AGS03610
      S=0.0                                                          AGS03620
      N=0                                                            AGS03630
      HAH=A                                                          AGS03640
      IF(BA) 20,19,20                                                AGS03650
   19 IER=1                                                          AGS03660
      RETURN                                                         AGS03670
   20 IF(DEL) 22,22,23                                               AGS03680
   22 IER=2                                                          AGS03690
      RETURN                                                         AGS03700
   23 IF(IMAX-1) 24,24,25                                            AGS03710
   24 IER=3                                                          AGS03720
      RETURN                                                         AGS03730
C                                                                    AGS03740
C     COMPUTE SIGMA(1)                                               AGS03750
   25 X=HA/2.0+A                                                     AGS03760
      NHALF=1                                                        AGS03770
      SUM=F(X,P)*HA=7.0/3.0                                          AGS03780
      S=SUMA+(F(A,P)+F(B,P))*HA/6.0                                  AGS03790
C                                                                    AGS03800
C     DIVIDE (A,B) INTO 2,4,...,2**I INTERVALS,                      AGS03810
C     COMPUTE SIGMA (2), SIGMA(4),...,SIGMA(I)                       AGS03820
C                                                                    AGS03830
      DO 28 I=2,IMAX                                                 AGS03840
      SI1=S                                                          AGS03850
      S=(S=SUMK/2.0)/2.0                                             AGS03860
      NHALF=NHALF*2                                                  AGS03870
      ANHLF=NHALF                                                    AGS03880
      FRST=A+(DA/ANHLF)/2.0                                          AGS03890
      SUM=F(FRSTX,P)                                                 AGS03900
      XK=FRSTX                                                       AGS03910
      KLAST=NHALF-1                                                  AGS03920
      FINC=BA/ANHLF                                                  AGS03930
      DO 26 K=1,KLAST                                                AGS03940
      XK=XK+FINC                                                     AGS03950
   26 SUM=SUM+F(XK,P)                                                AGS03960
      SUMK=SUMK*2.0*BA/(3.0*ANHLF)                                   AGS03970
      S=S+SUMK                                                       AGS03980
C                                                                    AGS03990
C     COMPARE THE I-TH AND (I-1)ST RESULTS                           AGS04000
C                                                                    AGS04010
   27 IF(ABS(S-SI1)-ABS(DEL*S)) 29,28,28                             AGS04020
   28 CONTINUE                                                       AGS04030
      IER=4                                                          AGS04040
      GO TO 30                                                       AGS04050
   29 IER=0                                                          AGS04060
   30 N=2**NHALF                                                     AGS04070
      RETURN                                                         AGS04080
      END                                                            AGS04090
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Program for Three Body Break Up Reaction

```
0001            FUNCTION F(X,P)                                          AGS04100
C                                                                        AGS04110
C               FUNCTION FOR SIMPSON INTEGRAL                            AGS04120
0002            DIMENSION P(10)                                          AGS04130
0003            PAI=3.1415927                                            AGS04140
0004            G=P(1)                                                   AGS04150
0005            V=P(2)                                                   AGS04160
0006            RH=P(3)                                                  AGS04170
0007            DH=P(4)                                                  AGS04180
0008            K=P(5)                                                   AGS04190
0009            IF(K+EQ.133) GOTO 20                                     AGS04200
0010          10 A=X+SIN(G+X/DH)                                         AGS04210
0011            B=1.0+EXP(X-RH/DH)                                       AGS04220
0012            F=A/B                                                    AGS04230
0013            RETURN                                                   AGS04240
0014          20 P=EXP(X-RH/DH)                                          AGS04250
0015            A=SIN(G*X/DH)+B                                          AGS04260
0016            F=A/(1.0+B)**2                                           AGS04270
0017            RETURN                                                   AGS04280
0018            END                                                      AGS04290
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0001            SUBROUTINE TIME(E1LMAX,E1LMIN,E2LMAX,E2LMIN,TH1MAX,TH2MAX  AGS04300
1,XM0,XM1,XM2,XM3,G,FPL,DFLFLL,TMLL,TM2L,PH12L,LMAX,LMIN                 AGS04310
1 ,ICODE)                                                                AGS04320
C                                                                        AGS04330
C     MASS IN ATOMIC MASS UNITS                                          AGS04340
C     ENERGY & VALUE IN MEV                                              AGS04350
C     LABORATORY ANGLES IN DEGREES                                       AGS04360
C     K=1 UPPER BRANCH, K=2 LOWER BRANCH                                 AGS04370
C                                                                        AGS04380
0002            COMMON /DATA/E1L(300),F2L(300,2),E23(300),E31(300,2),E12(300+2) AGS04390
1                    ,TH1C(300),TH2C(300,2),TH3C(300,2),THCP1(300,2)     AGS04400
1                    ,THCP2(300,2),THCP3(300,2),RHO1(300,2),RHO2(300,2)  AGS04410
1                    ,TH3L(300,2),PH13L(300,2)                           AGS04420
0003            DIMENSION PCX(3),PCY(3),PCZ(3),PC(3),THC(3),THCP(3),VRELX(3) AGS04430
1 ,VRELY(3),VRELZ(3),VREL(3)                                             AGS04440
0004          1 FORMAT(2OH UNACCEPTABLE ANGLES     )                    AGS04450
0005          2 FORMAT(18H0 REFLOW THRESHOLD     )                     AGS04460
0006          3 FORMAT(1H ,'TH1MAX=',F10.4,'     TH2MAX=',F10.4)       AGS04470
0007            ICODE=1                                                  AGS04480
0008            DO 752 I=1,300                                           AGS04490
0009        752 E2L(I,1)=0.0                                             AGS04500
0010            THLL=TM1L*3.1415927/180.0                                AGS04510
0011            TM2L=TH2L*3.1415927/180.0                                AGS04520
0012            PH12L=PH12L*3.1415927/180.0                              AGS04530
0013            XM=XM2+XM0+XM3                                           AGS04540
0014            XM31=XM3+XM1                                             AGS04550
0015            XM12=XM1+XM2                                             AGS04560
0016            XM23=XM2+XM3                                             AGS04570
0017            PP=SQRT(2.0*XM*FPL)                                      AGS04580
0018            VV=PP/(XM0+XM)                                           AGS04590
0019            A1=VV*SQRT(XM12/2.0)                                     AGS04600
0020            A2=VV*SQRT(XM23/2.0)                                     AGS04610
0021            ETOT=G+XM1+FPL/(XM0+XM)                                  AGS04620
0022            IF(ETOT) 250,250,251                                     AGS04630
0023        250 WRITE(6,2)                                               AGS04640
0024            ICODE=2                                                  AGS04650
0025            RETURN                                                   AGS04660
0026        251 C1L=COS(TH1LR)                                           AGS04670
0027            S1L=SIN(TH1LR)                                           AGS04680
0028            C2L=COS(TH2LR)                                           AGS04690
0029            S2L=SIN(TH2LR)                                           AGS04700
0030            CPH12L=COS(PH12LR)                                       AGS04710
0031            SPH12L=SIN(PH12LR)                                       AGS04720
C                                                                        AGS04730
C     COMPUTE MAXIMUM POSSIBLE ANGLES AND ENERGIES                       AGS04740
0032            E1CMAX=XM23+ETOT/XM                                      AGS04750
0033            E2CMAX=XM*G+ETOT/XM                                      AGS04760
0034            IF(A1**2-E1CMAX) 240,240,241                             AGS04770
0035        240 TH1MAX=180.0                                             AGS04780
0036            GO TO 911                                                AGS04790
0037        241 TH1MAX=ARCTAN(SQRT(E1CMAX)*SQRT(A1**2-E1CMAX))          AGS04800
0038        211 IF(A2**2-E2CMAX) 242,242,243                             AGS04810
0039        242 TH2MAX=180.0                                             AGS04820
0040            GO TO 213                                                AGS04830
0041        243 TH2MAX=ARCTAN(SQRT(E2CMAX)/SQRT(A2**2-E2CMAX))          AGS04840
```

```
0042        213 IF(TH1MAX-TH1L) 214,214,215                              AGS04850
0043        215 IF(TH2MAX-TH2L) 214,214,216                              AGS04860
0044        214 WRITE(6,1)                                               AGS04870
0045            WRITE(6,3) TH1MAX,TH2MAX                                 AGS04880
0046            ICODE=2                                                  AGS04890
0047            RETURN                                                   AGS04900
0048        216 T1=SQRT(E1CMAX-(A1*S1L)**2)                              AGS04910
0049            T2=SQRT(E2CMAX-(A2*S2L)**2)                              AGS04920
0050            E1LMAX=(A1*C1L+T1)**2                                    AGS04930
0051            IF(A1*C1L-T1) 220,220,221                                AGS04940
0052        220 E1LMIN=0.0                                               AGS04950
0053            GO TO 222                                                AGS04960
0054        221 E1LMIN=(A1*C1L-T1)**2                                    AGS04970
0055        222 E2LMAX=(A2*C2L+T2)**2                                    AGS04980
0056            IF(A2*C2L-T2) 223,223,224                                AGS04990
0057        223 E2LMIN=0.0                                               AGS05000
0058            GO TO 225                                                AGS05010
0059        224 E2LMIN=(A2*C2L-T2)**2                                    AGS05020
C                                                                        AGS05030
C     MAIN LOOP                                                          AGS05040
0060        225 DO 109 L=1,300                                           AGS05050
0061            FL=L                                                     AGS05060
0062            E1L(L)=FL*E1L+E1L                                        AGS05070
0063            IF(E1L(L)-E1LMAX) 103,103,111                            AGS05080
0064        101 E1C=E1L(L)-2.0*SQRT(E1L(L))*A1*C1L+A1**2                 AGS05090
0065            C1C=(SQRT(E1L(L))*C1L-A1)/SQRT(E1C)                      AGS05100
0066            E123=E1C*XM/XM23                                         AGS05110
0067            E23(L)=ETOT-E123                                         AGS05120
0068            IF(F23(L)) 109,109,102                                   AGS05130
0069        102 VS0=2.0*XM3*E23(L)/(XM2*XM23)                            AGS05140
0070            DVS0=2.0*XM3*XM*(A1*C1L/SQRT(E1L(L))-1.0)/(XM2*XM23**2)  AGS05150
0071            V23C=SQRT(2.0*XM1*E1C)/XM23                              AGS05160
0072            UX=V23C*SQRT(1.0-C1C*C1C)                                AGS05170
0073            UZ=VV-V23C*C1C                                           AGS05180
0074            US0=UX*UX+UZ*UZ                                          AGS05190
0075            ALPHA=UX*S2L*CPH12L+UZ*C2L                               AGS05200
0076            BETA=VS0-US0                                             AGS05210
0077            UXP=S1L*SQRT(XM1/(2.0*F1L(L)))/XM23                      AGS05220
0078            UZP=-C1L+SQRT(XM1/(2.0*E1L(L)))/XM23                     AGS05230
0079            ALPHAP=UXP*S2L*CPH12L+UZP*C2L                            AGS05240
0080            BETAP=DVS0+2.0*(UX*UXP+UZ*UZP)                           AGS05250
0081            P1=SQRT(2.0*XM1*F1L(L))                                  AGS05260
0082            PCX(1)=-P1*S1L                                           AGS05270
0083            PCY(1)=0.0                                               AGS05280
0084            PCZ(1)=P1*C1L-A1*SQRT(2.0*XM1)                           AGS05290
0085            PC(1)=SQRT(PCX(1)**2+PCZ(1)**2)                          AGS05300
0086            IF(ALPHA**2+BETA) 104,230,230                            AGS05310
0087        230 IF(BETA) 103,104,104                                     AGS05320
0088        103 N=2                                                      AGS05330
0089            GO TO 105                                                AGS05340
0090        104 N=1                                                      AGS05350
0091            E2L(L,2)=-0.0                                            AGS05360
0092            F31(L,2)=-0.0                                            AGS05370
0093            E12(L,2)=-0.0                                            AGS05380
0094            TH2C(L,2)=-0.0                                           AGS05390
0095            TH3C(L,2)=-0.0                                           AGS05400
0096            RHO1(L,2)=-0.0                                           AGS05410
0097            RHO2(L,2)=-0.0                                           AGS05420
0098            THCP1(L,2)=-0.0                                          AGS05430
0099            THCP2(L,2)=-0.0                                          AGS05440
0100            THCP3(L,2)=-0.0                                          AGS05450
0101        105 DO 106 K=1,N                                             AGS05460
0102            RTAB=SQRT(ALPHA**2+BETA)                                 AGS05470
0103            SGN=-(-1.0)**K                                           AGS05480
0104            E2L(L,K)=0.5*XM2*(ALPHA+SGN*RTAB)**2                     AGS05490
0105            P2=SQRT(2.0*XM2*F2L(L,K))                                AGS05500
0106            PDP2=PP*P2*C2L                                           AGS05510
0107            P1DP2=P1*P2*(C1L*C2L-S1L*S2L*CPH12L)                     AGS05520
0108            DENOM=SQRT((XM2*(-(PDP2-VPP2)*XM2/PP2**2)**2)            AGS05530
0109            RHO1(L,K)=XM1*XM2*XM3*P1DP2/DENOM                        AGS05540
0110            DE2=XM2*(ALPHA+SGN*RTAB)*(ALPHAP+SGN*(2.0*ALPHA*ALPHAP+BETAP)/(2.0AGS05550
1*RTAB))                                                                 AGS05560
0111            DS=SQRT(1.0+DE2*DE2)                                     AGS05570
0112            RHO2(L,K)=RHO1(L,K)/DS                                   AGS05580
0113            TH1C(L)=ARCTAN(SQRT(1.0-C1C**2)+C1C)                     AGS05590
0114            PCX(2)=PP*S2L+CPH12L                                     AGS05600
0115            PCY(2)=PP*S2L*SPH12L                                     AGS05610
0116            PCZ(2)=PP*C2L-A2*SQRT(2.0*XM2)                           AGS05620
0117            PC(2)=SQRT(PCX(2)**2+PCY(2)**2+PCZ(2)**2)                AGS05630
0118            PCX(3)=-PCX(1)-PCX(2)                                    AGS05640
0119            PCY(3)=-PCY(1)-PCY(2)                                    AGS05650
0120            PCZ(3)=-PCZ(1)-PCZ(2)                                    AGS05660
0121            PC(3)=SQRT(PCX(3)**2+PCY(3)**2+PCZ(3)**2)                AGS05670
0122            E31(L,K)=ETOT-XM*PC(2)**2/(2.0*XM23)                     AGS05680
0123            E12(L,K)=ETOT-XM*PC(3)**2/(2.0*XM3*XM12)                 AGS05690
0124            VRELX(1)=PCX(2)/XM2-PCX(3)/XM3                           AGS05700
0125            VRELY(1)=PCY(2)/XM2-PCY(3)/XM3                           AGS05710
0126            VRELZ(1)=PCZ(2)/XM2-PCZ(3)/XM3                           AGS05720
0127            VRELX(2)=PCX(3)/XM3-PCX(1)/XM1                           AGS05730
0128            VRELY(2)=PCY(3)/XM3-PCY(1)/XM1                           AGS05740
0129            VRELZ(2)=PCZ(3)/XM3-PCZ(1)/XM1                           AGS05750
0130            VRELX(3)=PCX(1)/XM1-PCX(2)/XM2                           AGS05760
0131            VRELY(3)=PCY(1)/XM1-PCY(2)/XM2                           AGS05770
0132            VRELZ(3)=PCZ(1)/XM1-PCZ(2)/XM2                           AGS05780
0133            VREL(1)=SQRT(VRELX(1)**2+VRELY(1)**2+VRELZ(1)**2)        AGS05790
0134            VREL(2)=SQRT(VRELX(2)**2+VRELY(2)**2+VRELZ(2)**2)        AGS05800
0135            VREL(3)=SQRT(VRELX(3)**2+VRELY(3)**2+VRELZ(3)**2)        AGS05810
0136            DO 203 I=1,3                                             AGS05820
0137            CTH=(PCX(I)*VRELX(I)+PCY(I)*VRELY(I)+PCZ(I)*VRELZ(I))/(PC(I)*  AGS05830
1VREL(I))                                                                AGS05840
0138            THCP(I)=ARCTAN(SQRT(1.0-CTH**2)+CTH)                     AGS05850
0139        203 CONTINUE                                                 AGS05860
0140            THCP1(L,K)=THCP(1)                                       AGS05870
0141            THCP2(L,K)=THCP(2)                                       AGS05880
0142            THCP3(L,K)=THCP(3)                                       AGS05890
0143            DO 205 I=2,3                                             AGS05900
0144            C1C=PCZ(I)/PC(I)                                         AGS05910
0145        205 THC(I)=ARCTAN(SQRT(1.0-C1C**2)+C1C)                      AGS05920
0146            TH2C(L,K)=THC(2)                                         AGS05930
0147            TH3C(L,K)=THC(3)                                         AGS05940
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      THTL(L,K)=ARCTAN(SQRT(PCX(3)**2+PCY(3)**2),(PCZ(3)+XM3*VV))
  106 PHI3L(L,K)=ARCTAN(PCY(3),PCX(3))
  109 CONTINUE
C
C     DETERMIN LMAX AND LMIN
  111 DO 253 L=1,300
      IF(F2L(L+1)) 253,253,254
  253 CONTINUE
  254 LMIN=1
      DO 255 L=LMIN,300
      IF(F2L(L+1)) 256,256,255
  255 CONTINUE
  256 LMAX=L+1
      RETURN
      END


      FUNCTION ARCTAN(Y,X)
      IF(X) 300,301,302
  300 IF(Y) 303,304,304
  303 ARCTAN=ATAN(Y/X)-3.1415927
      GO TO 308
  304 ARCTAN=ATAN(Y/X)+3.1415927
      GO TO 308
  301 IF(Y) 305,306,307
  305 ARCTAN=-3.1415927/2.0
      GO TO 308
  306 ARCTAN=0.0
      GO TO 308
  307 ARCTAN=3.1415927/2.0
      GO TO 308
  302 ARCTAN=ATAN(Y/X)
  308 ARCTAN=ARCTAN*180.0/3.1415927
      RETURN
      END
```

```
      SUBROUTINE PRINT(LMIN,LMAX,KCODE1,KCODE2,KCODE3)
      COMMON /ADATA/E1L(300),E2L(300),E23(300),E31(300),E12(300,2)
     1                ,TH1C(300),TH2C(300,2),TH3C(300,2),THCP1(300,2)
     1                ,THCP2(300,2),THCP3(300,2),RHO1(300,2),RHO2(300,2)
     1                ,TH3L(300,2),PHI3L(300,2)
      COMMON /AINPT/XM0,XM1,XM2,XM3,Q,EPL,TH1L,TH2L,PHI2L
      COMMON /PESON/COFF(4),ER(4),WIDTH(4)
      COMMON /OUTPT/A2(2,2,300),A3(2,2,300),AL2(2,2,300),AL3(2,2,300)
      DIMENSION A2GF(300),A2FS(300),A3GF(300),A3FS(300),
     1 A2GFSI(300),A3GFSI(300),AGFFSI(300)
      IF(KCODE3-EQ-0) GOTO 800
      WRITE(6,1001)
      GOTO(10,20,30),KCODE1
   10 WRITE(6,1002)
      GO TO 50
   20 WRITE(6,1003)
      GO TO 50
   30 WRITE(6,1004)
      GO TO 50
   50 CONTINUE
      K2=KCODE2+1
      GOTO(60,70,80),K2
   60 WRITE(6,1006)
      GO TO 90
   70 WRITE(6,1007)
      GO TO 90
   80 WRITE(6,1008)
   90 CONTINUE
      TB=0.0
      PB=1.0
      IF(KCODE2.EQ.1) TB=0.0
      IF(KCODE2.EQ.0) PB=0.0
      DO 120 L=LMIN,LMAX
      A2GF(L)=RHO1(L,1)*((TB*A2(1,1,L)+PB*A2(2,1,L))**2
     1+(TB*A2(1,2,L)+PB*A2(2,2,L))**2)
      A3GF(L)=RHO1(L,1)*((TB*A3(1,1,L)+PB*A3(2,1,L))**2
     1+(TB*A3(1,2,L)+PB*A3(2,2,L))**2)
      A2FS1(L)=RHO1(L,1)*((TB*AL2(1,1,L)+PB*AL2(2,1,L))**2
     1+(TB*AL2(1,2,L)+PB*AL2(2,2,L))**2)
      A3FS1(L)=RHO1(L,1)*((TB*AL3(1,1,L)+PB*AL3(2,1,L))**2
     1+(TB*AL3(1,2,L)+PB*AL3(2,2,L))**2)
      A2GFS1(L)=RHO1(L,1)*((TB*(A2(1,1,L)+AL2(1,1,L))+PB*(A2(2,1,L)+AL2
     2(2,1,L)))**2+(TB*(A2(1,2,L)+AL2(1,2,L))+PB*(A2(2,2,L)+AL2(2,2,L)))
     1**2)
      A3GFS1(L)=RHO1(L,1)*((TB*(A3(1,1,L)+AL3(1,1,L))+PB*(A3(2,1,L)+AL3
     2(2,1,L)))**2+(TB*(A3(1,2,L)+AL3(1,2,L))+PB*(A3(2,2,L)+AL3(2,2,L)))
     1**2)
      AGFFSI(L)=RHO1(L,1)*((TB*(A2(1,1,L)+A3(1,1,L)+AL2(1,1,L)+AL3(1,1,L
     1))+PB*(A2(2,1,L)+A3(2,1,L)+AL2(2,1,L)+AL3(2,1,L)))**2
     1+(TB*(A2(1,2,L)+A3(1,2,L)+AL2(1,2,L)+AL3(1,2,L))
     1+PB*(A2(2,2,L)+A3(2,2,L)+AL2(2,2,L)+AL3(2,2,L)))**2)
  120 CONTINUE
      K3=KCODE3+1
      GOTO(800,200,300,400,500),K3
  200 CONTINUE
      WRITE(6,1020)
      WRITE(6,1021)
      DO 280 L=LMIN,LMAX
      WRITE(6,1022) E1L(L),A2(1,1,L),A2(1,2,L),A3(1,1,L),A3(1,2,L)
     1,AL2(1,1,L),AL2(1,2,L),AL3(1,1,L),AL3(1,2,L)
      WRITE(6,1023) A2(2,1,L),A2(2,2,L),A3(2,1,L),A3(2,2,L)
     1,AL2(2,1,L),AL2(2,2,L),AL3(2,1,L),AL3(2,2,L)
  280 CONTINUE
      GOTO 999
  300 CONTINUE
      WRITE(6,1030)
      DO 380 L=LMIN,LMAX
      WRITE(6,1031) E1L(L),A2GF(L),A3GF(L),A2FS1(L),A3FS1(L),A2GFS1(L)
     1,A3GFS1(L),AGFFSI(L)
  380 CONTINUE
      GOTO 999
  400 CONTINUE
      WRITE(6,1040)
      DO 480 L=LMIN,LMAX
      E3L=EPL-E1L(L)-E2L(L,1)
      WRITE(6,1041) E1L(L),E2L(L,1),E3L,E23(L),TH1C(L),THCP1(L,1),
     1A3FS1(L),A2GFS1(L),A3GFS1(L),AGFFSI(L)
  480 CONTINUE
      GOTO 999
  500 CONTINUE
      WRITE(6,1050)
      DO 580 L=LMIN,LMAX
      E3L=EPL-E1L(L)-E2L(L,1)
      WRITE(6,1051) E1L(L),E2L(L,1),E3L,E23(L),TH1C(L),THCP1(L,1),
     1A2GF(L),A3GF(L),A2FS1(L),A3FS1(L),A2GFS1(L),A3GFS1(L),AGFFSI(L)
  580 CONTINUE
      GOTO 999
  800 CONTINUE
      WRITE(6,1080)
      DO 880 L=LMIN,LMAX
      E3L=EPL-E1L(L)-E2L(L,1)
      WRITE(6,1081) E1L(L),E2L(L,1),E3L,E23(L),RHO1(L,1),TH1C(L),
     1THCP1(L,1),E31(L,1),TH2C(L,1),THCP2(L,1),E12(L,1),TH3C(L,1),
     1THCP3(L,1)
  880 CONTINUE
  999 CONTINUE
      RETURN
 1001 FORMAT(1H0,' REACTION MECHANISM')
 1002 FORMAT(1H ,'KM3 IS NOT A COMPOSIT PARTICLE')
 1003 FORMAT(1H ,'KM3= KM1+KM2 AND BREAKS TO SINGLET DEUTERON')
 1004 FORMAT(1H ,'KM3= KM1+KM2 AND BREAKS TO TRIPLET P-N SYSTEM')
 1006 FORMAT(1H ,'TARGET BREAK UP REACTION')
 1007 FORMAT(1H ,'PROJECTILE BREAK UP REACTION')
 1008 FORMAT(1H ,'TARGET BREAK + PROJECTILE BREAK')
 1020 FORMAT(1H ,'  E1L        A2RT        A2IT        A3RT        A3L
     1T        A2LRT       A2LIT       A3LRT       A3LIT')
 1021 FORMAT(1H ,'  A2RP        A2IP        A3RP        A3IP
     1  A2LRP       A2LIP       A3LRP       A3LIP')
 1022 FORMAT(1H ,F7.3,8(1X,E12.4))
 1023 FORMAT(1H ,2X,8(2X,E12.4))
 1030 FORMAT(1H ,'  E1L         C2GF        C3GF        C2FSI       C3FS
     1I        C2GFSI      C3GFSI      C6FFSI')
 1031 FORMAT(1H ,F7.3,7(1X,E12.4))
 1040 FORMAT(1H ,'  E1L         E2L         E3L         E23         C2GF
     1        C3GF        C2FSI       C3FSI       C6FFSI')
 1041 FORMAT(1H ,F7.3,7(1X,E12.4))
 1050 FORMAT(1H ,'  E1L         E2L         E3L         E23         TH1C
     1        THCP1       C2GF        C3GF        C2FSI       C3FSI
     1FSI')
 1051 FORMAT(1H ,4(F8.2,1X),7(1X,E11.4))
 1080 FORMAT(1H1,'E1L(',I3,')=',F8.4,' E2L(',I3,')=',F8.4,' E3L(',I3,')='
     1,F8.4,' E23(',I3,')=',F8.4,' RHO1(',I3,')=',F8.4,' TH1C(',I3,')='
     2,F8.4,' THCP1(',I3,')=',F8.4,' E31(',I3,')=',F8.4,' TH2C(',I3,')='
     3,F8.4,' THCP2(',I3,')=',F8.4,' E12(',I3,')=',F8.4,' TH3C(',I3,')='
     4,F8.4,' THCP3(',I3,')=',F8.4)
 1081 FORMAT(1H ,3X,F10.4,12(2X,F9.4))
      END
```